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Soil Property Changes During Loblolly Pine Production

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Abstract. Three watersheds, each approximately 25 ha, were instrumented to measure and record drainage rate, water table depth, rainfall and meteorological data. Data continuously collected on the site since 1988 include response of hydrologic and water quality variables for nearly all growth stages of a Loblolly pine plantation. Data for drainage outflow rates and water table elevations were used to determine field effective hydraulic conductivity, K, of the profile at various stages of the production cycle. K values of the top 90 cm of the profile for mature plantation forest were 60 to 95 m/day, which are 20 to 30 times the values given in the soil survey for the Deloss series. Harvest did not appear to affect those values, but site preparation for regeneration, including bedding, reduced the effective K to values typically assumed for this series, 3.6 m/d for the top 45 cm and 1.6 m/d for deeper layers.

KEYWORDS. Water table, Drainage, Forest, Hydraulic Conductivity, Harvesting

maintained as the control with standard drainage and silvicultural practices. The other two watersheds have been subjected to a range of silvicultural and water management practices, and studies have been conducted on the hydrologic and water quality impacts of those practices over the 20 year history of this site. The studies are summarized in Table 1.

Table 1. Summary of studies on the Carteret 7 Experimental Watersheds

Subject of Study	Dates	Principle References, Theses and Journal Articles Describing Results
General Hydrology	1988-2005	McCarthy (1990); McCarthy et al. (1991; 1992); McCarthy and Skaggs (1992); Amatya (1993); Amatya et al. (1997); Richardson and McCarthy (1994); Chescheir et al.(2003); Sun et al.(2002; 2005)Amatya et al.(2006a)
Controlled Drainage, Orifice Weir	1990-1999	Amatya et al. (1996; 1998; 2000; 2003); Amatya and Skaggs(1997)
Methods for Predicting ET	1990-	McCarthy et al.(1992); Amatya et al.(1995); Lu et al.(2003); Lu(2002);
Hydrologic Simulation Models	1988-2005	McCarthy(1990); McCarthy and Skaggs(1991; 1992); McCarthy et al.(1992); Amatya (1993); Amatya et al.(1997b; 2001; Amatya and Skaggs (201)
Effects of Harvesting and Regeneration		Blanton et al.(1998); Amatya et al. (2006b); Sun et al.(2001)
Water Quality Impacts	2005-2006	Smith (1994); Amatya et al.(1998; 2003); Chescheir et al.(2003)
Effects of Fertilization	2005-	Watershed 3 fertilized in 2005, no results yet.

Hydrology

Trees on the watersheds were 15 years old when observations began in 1988. The hydrology has been intensively measured for over 17 years with results documented in several publications (Table 1). Amatya et al. (2006a) summarized the hydrology of watershed D1 for the 17 year period as the trees aged from 15 to 32 years. These results will be only briefly summarized herein. Watershed D2 was harvested in June1995 and replanted in January 1997, so we have hydrologic data for the effects of harvesting and regeneration, as well as for years 1-7 of the production cycle.

The principle hydrologic components for drained forested watersheds in the coastal plain are rainfall, evapotranspiration (ET), subsurface drainage, and surface runoff. Deep and lateral seepage are generally small for these flat poorly drained watersheds (McCarthy et al., 1991). Most of the drained plantation soils are bedded such that surface depressional storage is large (several cm) and surface runoff is small and, in most cases negligible. Rainfall interception is relative large, amounting to 18 to 27% of total rainfall (McCarthy et al., 1991). Intercepted rainfall is ultimately evaporated and is usually considered, in a water balance, as part of the ET component. Based on an analysis of data from the D1 watershed for the 17 year period of record, Amatya et al. (2006) reported the following statistics for the water balance components. Annual rainfall ranged from 852 to 2331 mm with an average of 1538 mm. Annual outflow, the sum of subsurface drainage and surface runoff, averaged 541 mm, and ET, calculated as the difference in rainfall and outflow, averaged 997mm per year. The annual runoff coefficient

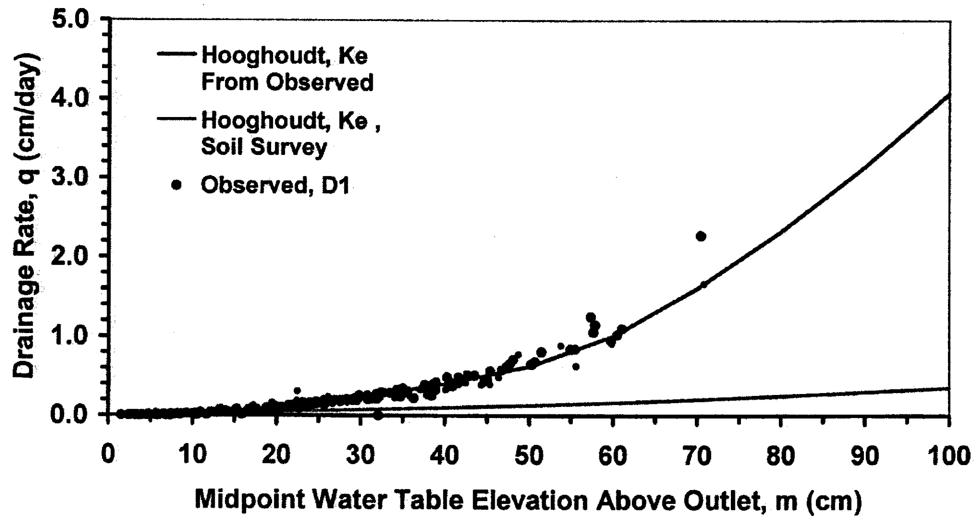

Figure 1. Relationship between drainage rate and water table elevation above water level in ditch as observed for watershed D1 and calculated by Hooghoudt Equation for D1 and from K data in Soil Survey.

The high K values in the top 90 cm of the profile (Table 1) are attributed to the presence of large pores that result from tree roots and biological activity that is uninterrupted for many years in a forest. Similar high K values were reported by Grace (2003) for an organic soil on the Parker tract in eastern NC, and by Skaggs et al. (2004) for a mineral soil on the same tract. Both sites were in plantation forest. The high K values and consequent rapid drainage rates resulted in very few data points for m values greater than 60 cm for watershed 1 (Figure 1). The profile drained rapidly and the water table rarely rose to an elevation greater than 60 cm above the water level in the ditches. Drainage rates on this forested site were particularly rapid compared to those predicted using published hydraulic conductivity values for the Deloss soil series (Figure 1). These values, which are characteristic of this soil for agricultural land uses, resulted in predicted drainage rates that were close to those measured on D1 for deep water tables (m less than 15 cm), but less than 10% of the measured D1 drainage rates for water table depths less than 40 cm (m values greater than 60 cm).

The rapid drainage rates observed on D1 will not occur on all forested sites, and not for all conditions on these sites, as will be shown later in this paper. A more complete picture of the relationship between drainage rate and water table depth is given in Figures 2 and 3. The drainage rate is plotted as a function of m in Figure 2; the water table shape corresponding to various depths is shown in Figure 3. Most of the time the water table is below the ground surface and has an elliptical shape as illustrated by positions 1 and 2 in Figure 3 with corresponding drainage rates indicated by points 1 and 2 in Figure 2.

predicted with methods developed by Kirkham (1957). Continued rainfall at rates greater than the drainage rate will result in surface runoff. Because of large surface depressional storage and rapid subsurface drainage rates, surface runoff from the Carteret 7 watersheds was rare, only occurring during hurricanes and intensive tropical storms.

In most cases drainage rates are limited by the rate water will move through the soil profile to the ditches as discussed above. Another factor controlling drainage rates, especially during extreme events, is the hydraulic capacity of the drainage network, commonly referred to as the drainage coefficient, DC. This capacity is dependent on the size and slope of the outlet drainage ditches and canals. When water moves to the field drains at rates greater than the DC, the drainage rate is limited to the DC, as shown in Figure 2, and water will back up in the ditches and the surface will likely become ponded. A pump was installed to increase the DC to about 7 cm/day on the experimental sites. However, the DC is also limited by ditch capacity which was sometimes reduced due to vegetation and silting, so the effective DC was about 5 cm/day for most of the period of observation. Although this is a relatively high DC, it is less than the maximum rate that water will drain to the ditches, as shown in Figure 2. Nearly all occasions of surface ponding during the 17 years of observations have resulted from limitations of the outlet capacity, often as a result of pump failure due to loss of electrical power. Such failures usually resulted in submergence of the outlet weirs and a short term loss of flow record.

Effect of Harvesting and regeneration

The effect of harvesting and regeneration was studied in 1995 and following and is discussed in detail by Amatya et al. (2006b, this volume). Watershed D2 was harvested in July 1995 at a stand age of 21 years. The watershed was bedded and prepared for planting in October 1996 and planted in February 1997. Continuous flow and water table records were analyzed to determine the hydrologic and water quality effects and their change with time after replanting. Harvest reduced ET and water table depth and increased drainage outflow and runoff coefficient compared to the control (D1) which was not harvested. Results for the control were used with calibration from previous years to determine expected outflows from unharvested D2 on an annual basis. These values were compared to measured outflows for D2 to determine the effects of harvest. Results are summarized in Table 3 for the 5 year period following harvest 1995-1999. Analysis of the flow data through 2004 indicated that outflow from D2 may not have yet returned to the base line conditions prior to harvest.

Table 3. Summary of hydrologic components for the control watershed D1 and of the effects of harvesting and regeneration on ET and drainage. Values for D2 (expected) are based on measurements for D1 multiplied by the ratio D2/D1 for the calibration period (after Amatya et al., 2006, this volume).

	Hydrology Conventional Drainage D1, 1988-2004	Harvesting and Regeneration 1995-1999 D2 (expected)	D2(harvested)	%Change
Rainfall (mm)	1538	1307	1307	
ET (mm)	997	833	598	28 %
Drainage (mm)	541	474	709	49 %
Runoff Coefficient	0.33	0.32	0.51	59 %

to determine K_e, are plotted in Figure 4. The predicted relationship for watershed D1 is plotted in Figure 4 for comparison. The hydraulic conductivity for the top 45 cm of the profile in D2 (pre-bedding) is smaller than for D1. However, K for the 45 to 90 cm depth for D2 is larger than D1 (Table 1).

The relationship for post-bedding is much reduced compared to pre- and post-harvest conditions. Predictions by the Hooghoudt equation, using the high end of the range of K values given in the Soil Survey for Deloss soil (Table 1), agreed very well with the observations for post-bedding condition (Figure 4). Apparently the bedding process destroyed the macro-pores in the surface layers such that the profile had effective K values similar to that expected for agricultural crop production. These data indicate that it was not the harvesting process that reduced the K values in the top part of the profile back to levels expected for agricultural uses on this soil series, but the bedding process prior to replanting.

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References

Amatya, D.M. 1993. Hydrologic Modeling of Drained Forested Lands. Ph.D. Dissertation, Biological & Agricultural Engineering, North Carolina State University, Raleigh, NC, 210 p.

Amatya, D.M. and R.W. Skaggs. 2001. Hydrologic modeling of pine plantations on poorly drained soils. *Forest Science*. 47(1): 103–114.

Amatya, D.M., R.W. Skaggs and J.D. Gregory. 1995. Comparison of Methods for Estimating REF-ET. *J. of Irrigation & Drainage Engr.*, Nov./Dec. 1995, Vol. 121, No. 6, pp: 427-435.

Amatya, D.M., R.W. Skaggs, and J.D. Gregory. 1996. Effects of Controlled Drainage on the Hydrology of a Drained Pine Plantation in the Coastal Plains. *J. of Hydrology*, 181: 211-232.

Amatya, D.M., R.W. Skaggs and J.D. Gregory. 1997a. Evaluation of a Watershed Scale Forest Hydrologic Model. *Journal of Agricultural Water Management*, 32(1997):239-258.

Amatya, D.M., R.W. Skaggs, J.D. Gregory, R.B. Herrmann. 1997b. Hydrology of a drained forested pocosin watershed. *J. of the American Water Resources Association,* 33(3):535-546.

Amatya, D.M., J.W. Gilliam, R.W. Skaggs, M.E. Lebo and R.G. Campbell. 1998. Effects of controlled drainage on forest water quality. *Journal of Environmental Quality*. 27: 923–935.

Amatya, D.M., J.D. Gregory, and R.W. Skaggs. 2000. Effects of controlled drainage on storm event hydrology in a loblolly pine plantation. *Journal of the American Water Resources Association*, 36(1):175-190.

Amatya, D.M., R.W. Skaggs, J.W. Gilliam, and J.E. Hughes. 2003. Effects of an orifice-weir outlet on the hydrology and water quality of a drained forested watershed. *South. J. Appl. For.*, 27(2): 130-142

Amatya, D.M., R.W. Skaggs, and J.W. Gilliam. 2006a. Hydrology and water quality of a drained loblolly pine plantation in Coastal North Carolina. Proc, Int'l Conference on Hydrology and Management of Forested Wetlands, ASABE, St Joe, MI. This volume.

SCS. 1978. Soil Survey of Carteret County North Carolina. USDA, SCS. 155p

Skaggs, R.W., G.M. Chescheir, G.P. Fernandez, and D.M. Amatya. 2004. Effects of Land Use on the Hydrology of Drained Coastal Plain Watersheds. In M.S. Altinakar, S.S.Y. Wang, K.P. Holz. and M. Kawahara (eds.) Proc. of the 6th Int'l Conf. on Hydro-Science and Engineering, Brisbane, Australia, May 31-June 3.

Smith, K.L. 1994. Assessing Water Quality Impacts of Forest Management Activities in Pocosin Wetlands in eastern North Carolina. M.S. Thesis,University of Georgia, Athens, GA.

Sun, G., S.G. McNulty, D.M. Amatya, R.W. Skaggs, L.W. Swift Jr., J.P. Shepard, and H. Riekerk. 2002. A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the southern US. *J. of Hydrology*, 263(2002):92-104.

Sun, G., S.G. McNulty, J.Lu, D.M. Amatya, Y. Liang, and R.K. Kolka. 2005. Regional annual water yield from forest lands and its response to potential deforestation across the southeastern United States. *J. of Hydrology*, 308(2005):258-268.

Van der Ploeg, R.R., R. Horton and D. Kirkham. (1999). "Steady flow to drains and wells". P213-264 In R.W. Skaggs and J. van Schilfgaarde (ed.) Agricultural Drainage, SSSA, Madison WI